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OPTIMIZATION OF GRAVITY RETAINING WALL PROFILE BY INTRODUCING CAVITY

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ABSTRACT

The aim of this paper is to develop a cost effective and structurally efficient profile of gravity retaining wall by introducing cavity in the section. For this, various section sizes of gravity retaining wall are analyzed and accordingly profile is selected. After selection of an appropriate profile of gravity retaining wall stability calculations are carried out for various heights using ‘C’ programming by strength of material approach. Section is further analyzed by finite element method by using software ANSYS.

Rectangular and circular cavities are introduced in the section for various heights and is analyzed by strength of material approach (C program) as well as by finite element approach (ANSYS).

KEYWORDS: Principles of Design, Finite Element Analysis, Plane Stress Problem, Plane Strain Problem, Rectangular Cavity, Circular Cavity,ANSYS

INTRODUCTION

The retaining wall or retaining structure is used for maintaining ground surface at different elevations on either side of it. Retaining walls are usually necessary whenever embankments are involved in construction, in the construction of buildings having basements and in bridge work where the wing walls and abutments are designed as retaining walls, to resist earth pressure along with superimposed load.

The gravity retaining wall is one in which the earth pressure exerted by the backfill is resisted by dead weight of the wall, which is either made up of masonary or of mass concrete. The design of retaining wall is trial and error process and the profiles of retaining walls are so proportioned that the stress developed in the wall is very low and no tension is developed anywhere in the section, and the resultant of forces lie within the middle third of the base. The retaining wall is checked for sliding, overturning and bearing capacity failure.

When we analyze the retaining wall it is observed that the factor of safety against overturning increases beyond the safe limit while factor of safety against sliding just reaches to its safe limit. Due to this unevenness, the cross sections of solid gravity retaining wall provided from the consideration of stability checks remain unutilized i.e. material in section remains unstressed and it leads to inefficient section. Thus, the cross section satisfying the prescribed conditions can be effectively utilized by introducing cavities in the section. Removal of the material may cause instability in the section which can be easily overcome by providing preventive measures like shear key.The cavity not only makes the wall

structurally efficient but is also economically feasible.

Such a solid gravity wall with cavity can be used for different purposes like accommodating services such as water mains, telephone lines, electrical cables, sewage pipes, water drainage, etc.

PRINCIPLES OF THE DESIGN OF RETAINING WALL

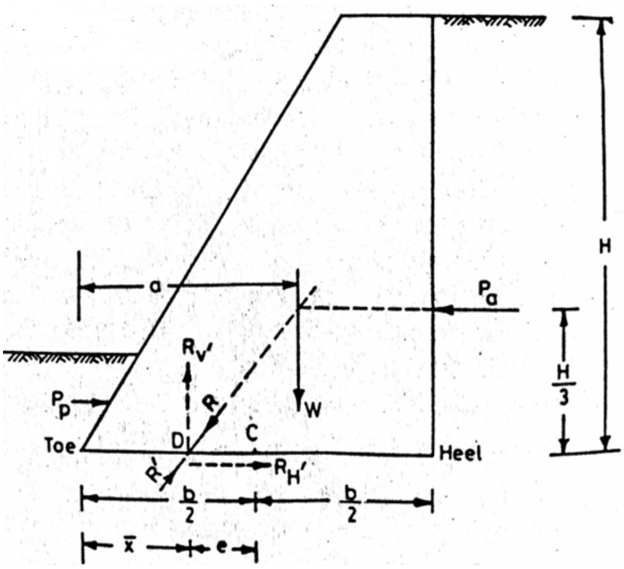

Figure 1: Forces Acting on Retaining Wall

Figure 1 shows a retaining wall with a smooth back face and no surcharge. The active pressure P_a acts horizontally, as shown. The front face of the wall is subjected to a passive pressure (P_p) below the soil surface. However, it is doubtful whether the full passive resistance would develop. Moreover, often P_p is small and therefore it may be neglected. This gives more conservative design.

The weight *W* of the wall and the active pressure P_a have their resultant *R* which strikes the base at point D. There is an equal and opposite reaction R' at the base between the wall and the foundation. For convenience, R' is resolved into vertical and horizontal component (R_V'andR_H').

From the equilibrium of the system,

$R_V' = W$ and$R_H' = P_a$

The third equation of equilibrium, namely the moment equation, is used to determine the eccentricity *e* of the force R_V'relative to the center C of the base of the wall. Obviously, by taking moments about the toe,

$R_V \times \bar{x} = W \times a - P_a \times (H/3)$

$$\bar{x} = \frac{W \times a - P_a \times \left(\frac{H}{3}\right)}{R_V'} \quad (1)$$

Where, $\bar{x}$ is the distance of the point D from the toe.

Thus, eccentricity, $e = (b/2) - \bar{x}$ (2)

Where, b = width of the base.

For a safe design, the following requirements must be satisfied.

- **Check for Sliding**

The wall must be safe against sliding. In other words,

$\mu R_V > R_H$

Where, R_V and R_H are vertical and horizontal components of R, respectively. The factor of safety against sliding is given by

$F_S = \mu R_V / R_H$ (3)

Where, μ = coefficient of friction between the base of the wall and the soil (= tan δ)

A minimum factor of safety against sliding is taken from IS-456 (2000), cl. no. 20.2.

- **Check for Overturning**

The wall must be safe against overturning about toe. The factor of safety against overturning is given

$F_O = \sum M_R / \sum M_O$ (4)

where, $\sum M_R$ = sum of resisting moment about toe, and $\sum M_O$ = sum of overturning moment about toe.

In figure, $F_O = (W \times a) / (P_a \times H/3)$ (5)

A minimum factor of safety against overturning is taken from IS-456 (2000), cl. no. 20.1.

- **Check for Bearing Capacity Failure**

The pressure caused by R_V at the toe of the wall must not exceed the allowable bearing capacity of the soil.

The pressure distribution at the base is assumed to be linear. The maximum pressure is given by

$p_{max} = (R_V / b)(1 + 6e/b)$ (6)

The factor of safety against bearing failure is given by

$F_b = q_{na} / p_{max}$ (7)

Where, q_{na} = allowable bearing pressure.

A factor of safety of 3 is usually specified, provided the settlement is also within the allowable limit.

FINITE ELEMENT ANALYSIS

The finite element analysis is a numerical technique. In this method all the complexities of the problems like varying shapes, boundary conditions and loads are maintained as they are but the solution obtained are approximate. Because of its diversity and flexibility as an analysis tool, it is receiving much attention in engineering. This method is used extensively for the analysis in solid mechanics and also used in various field of civil engineering such as structural analysis, analysis of foundation, rock mechanics, etc. In engineering problem there are some basic unknowns. If they are found, the behavior of entire structure can be predicted. These unknowns which are called as field variables are infinite.

The finite element procedure reduces such unknowns to finite number by dividing the solution region in to smaller part called as elements.

In finite element approach analysis is based on whether it is 2D problem or 3D problem depending upon actual forces acting on the structures and the response to it. Generally two types of distribution arise in the 2D analysis. These are termed as plane stress problem and plane strain problem.

- **Plane Stress Problem**

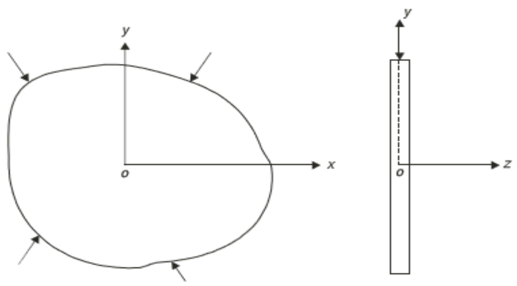

Figure 2: Plane Stress Problem

The thin plate subjected to forces in their plane only, falls under the category of plane stress problem. Figure 2 shows a typical plane stress problem. In this case there is no force in Z-direction and no variation of any forces in z-direction. Hence, $\sigma_z = \tau_{xz} = \tau_{yz} = 0$.

- **Plane Strain Problem**

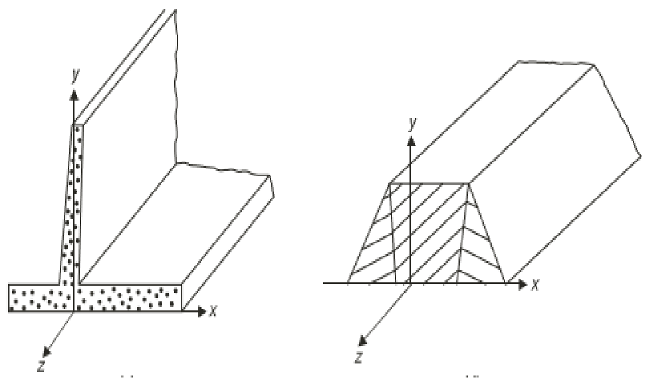

Figure 3: Plane Strain Problem

A long body subject to significant lateral forces but very little longitudinal forces falls under the category of plane strain problem. Examples of such problems are pipes, long strip footings, retaining walls, gravity dams, tunnels, etc. (refer figure 3). The displacement in longitudinal direction (z-direction) is zero in typical strip. Hence the strain components, $\epsilon_z = \gamma_{xz} = \gamma_{yz} = 0$.

The problem which is considered in this dissertation is analysis of retaining wall. This particular problem falls under the category of plane strain problem. Before studying various steps of final element approach, elasticity part has to be consideredforanalyzingtheproblem.

PROFILE SELECTION

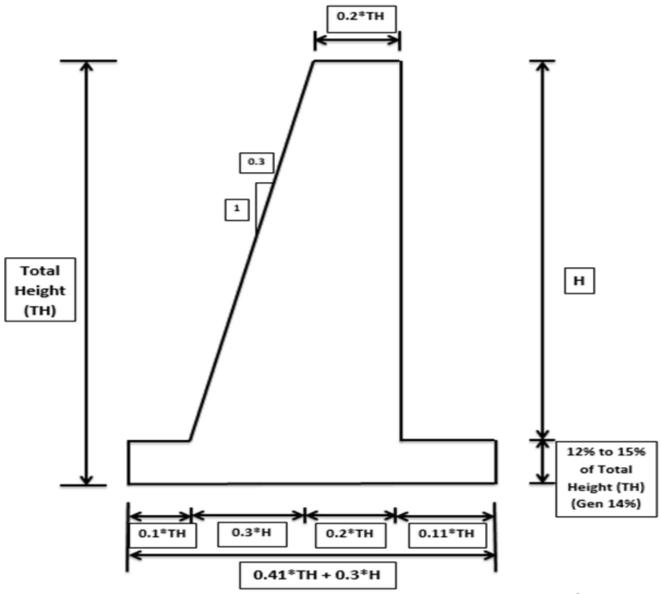

Figure 4: Profile of Dry Backfill

Various profiles of gravity retaining wall are analyzed and finally those dimensions that gave least factor of safety were accepted. The wall geometry is shown in figure. The gravity retaining wall was analyzed by strength of material approach using 'C' programming and finite element analysis for the same is carried out by using ANSYS software. 8-noded quadrilateral element was used for finite element analysis of gravity retaining wall.

OBSERVATIONS AND RESULTS

Variation of Stresses against Various Heights for Walls without Cavity

Graph G-1 variation of stresses Pmax and Pmin against various heights for walls without cavity. From the graph it is observed that stresses increases with increase in height.

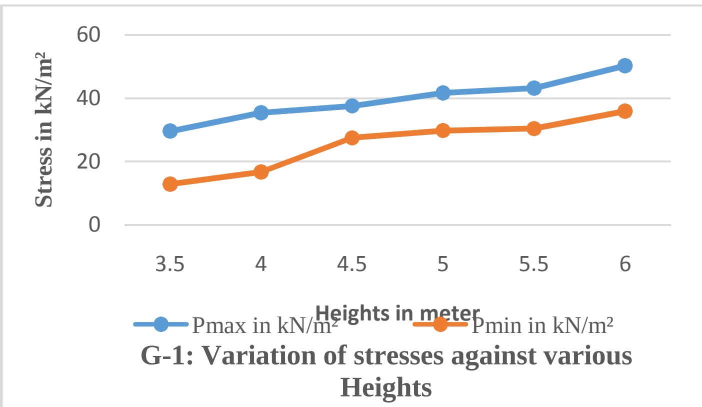

Figure 5

Variation of Ratio of Stresses to Permissible Stresses against Ratio of Cavity Depth to Stem Height in case of Rectangular Cavity

Following graphs are the output results for the cavity position 0.25m from stem backfill face and 0.25m from base of the stem. Graph G-2 shows the variation of ratio of maximum compressive stresses developed in the wall to the

permissible stresses (σ_c/σ_{cbc})against the ratio of cavity depth to stem height. Graph G-3 shows the variation of ratio of maximum tensile stresses developed in the wall to the permissible stresses (σ_t/σ_{ac})against the ratio of cavity depth to stem height. From the graphs it is seen that for larger cavity size, stresses induced are more but in the permissible limit whereas for smaller cavity size stresses induced are less. Using these graphs one can find the optimum size of cavity for which both the tensile and compressive stresses yields best results.

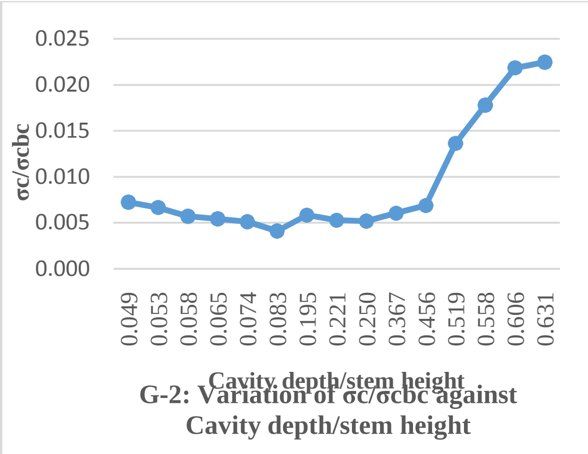

Figure 6

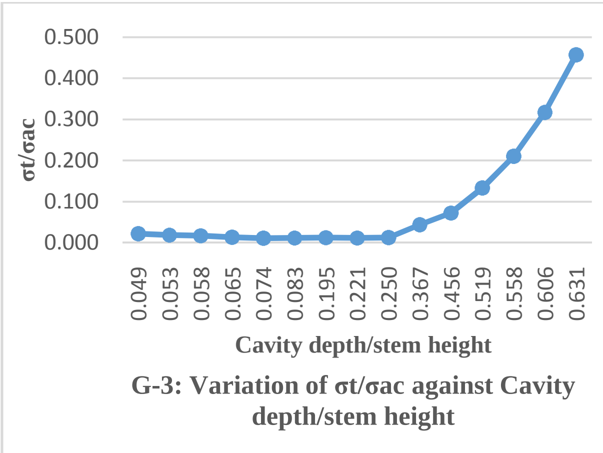

Figure 7

Variation of Ratio of Stresses to Permissible Stresses against Ratio of Cavity Diameter to Stem Height in case of Circular Cavity:

Following graphs are the output results for the cavity position 0.25m from stem backfill face and 0.25m from base of the stem. Graph G-4 shows the variation of ratio of maximum compressive stresses developed in the wall to the permissible stresses (σ_c/σ_{cbc})against the ratio of cavity diameter to stem height. Graph G-5 shows the variation of ratio of maximum tensile stresses developed in the wall to the permissible stresses (σ_t/σ_{ac})against the ratio of cavity diameter to stem height. From the graphs it is seen that for larger cavity size, stresses induced are more but in the permissible limit whereas for smaller cavity size stresses induced are less. Using these graphs one can find the optimum size of cavity for which both the tensile and compressive stresses yields best results.

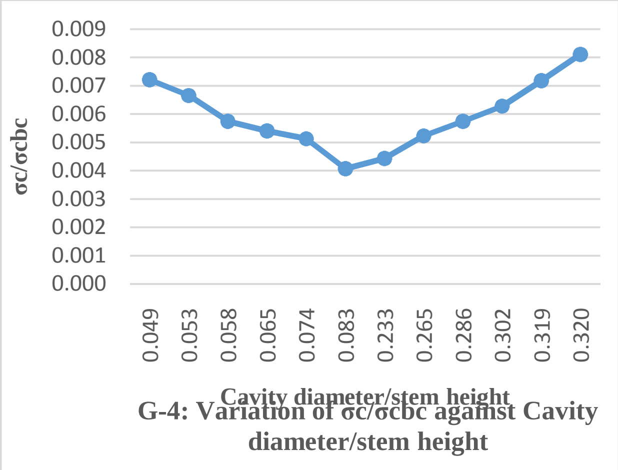

Figure 8

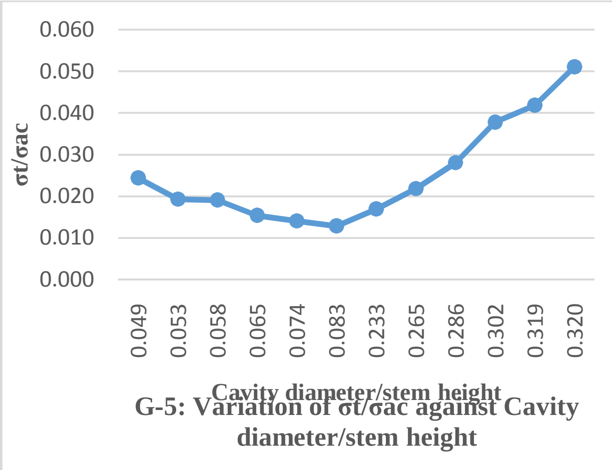

Figure 9

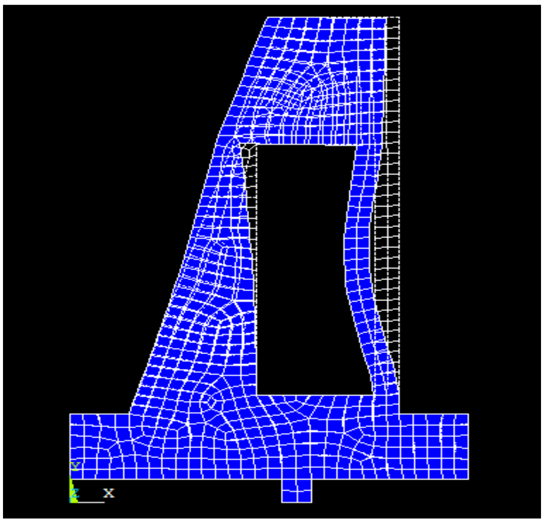

Figure 10:Retaining Wall with Height = 6.0m, Cavity Size = 1.2m X 3.25m, Saving of Material = 27.99%

Figure 10 shows deformed and undeformed shape of retaining wall with 6.0m height and cavity size 1.2m X 3.25m with 0.25m offset from base of stem and backfill face of stem.

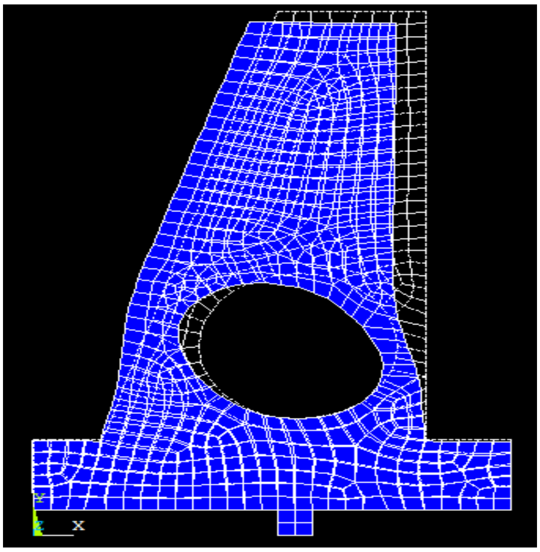

Figure 11: Retaining Wall with Height = 6.0m, Cavity Diameter = 1.65m, Saving Of Material = 15.05%

Figure 11 shows deformed and undeformed shape of retaining wall with 6.0m height and cavity diameter 1.65m with 0.25m offset from base of stem and backfill face ofstem.

CONCLUSIONS

On the basis of results obtained, discussed and interpreted in previous chapter following conclusions are drawn.

- **Solid Gravity Walls**

Solid gravity walls are not structurally efficient systems as well as these are costlier than other types of wall. Hence, to obtain structurally efficient as well as an economically feasible solution, cavities may be introduced in the wall.

- **Rectangular Cavities**
  - The performance of retaining wall section with cavity depends on its distance from vertical face of stem, maximum stress increases as this distance reduces.
  - As cavity extends to highly stressed zone it attracts increasingly high stresses.
  - Zone of maximum tension depends on portion of cavity and its aspect ratio. Tension zone is observed at right bottom corner of cavity.
  - For slender cavities shows reverse curvature.
  - Rectangular cavities yields largest saving in the material up to 28%.
  - Rectangular cavity use material capacity in better manner, however, still there is a larger reserved strength that remains unutilized.
- **Circular Cavities**
  - Walls with circular cavity are very structurally efficient form of retaining wall.
  - Largest single cavity does show that very large function of material strength remains unused. Hence, such cavities may be used as multiple cavities or in combination with other types of cavities to yield better results.

- Saving of material is up to 15%.
- Saving of material achieved in case of walls with circular cavity is almost half the saving of material achieved in walls with rectangular cavity. Due to circular shape of the cavity limited cases are available for analysis as compared to the rectangular type of cavity.

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